IN THE SPECIFICATION:

Please amend the specification as follows:

Please insert the following heading and paragraphs prior to the Best Mode of the Invention heading:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1. is an exemplary network topology for application of methods of the invention and used in a numerical simulation of an embodiment of the invention;

FIG. 2 is a graph of total average transmit power versus network throughput for three cluster schedules X, Y and Z reached in a numerical simulation and applied to the network topology of FIG. 1;

FIG. 3 is a graph of total average transmit power versus network throughput for the cluster schedules X, Y and Z reached in a numerical simulation and applied to the network topology of FIG. 1;

FIG. 4 is an example transport style network for application of methods of the invention and used in a numerical simulation of an embodiment of the invention;

FIG. 5 plots the ratio of throughputs achieved by scheduling in accordance with the invention compared to TDMA with increasing values of ambient noise for the network topology of FIG. 4;

FIG. 6 plots the total average power with increasing traffic rates for the session between node 1 and node 5 in the network topology of FIG. 4;

FIG. 7 illustrates an example asymmetric diamond topology for application of methods of the invention and used in a numerical simulation of an embodiment of the invention;

FIG. 8 plots throughput ratios for simulations on the FIG. 7 network topology;

FIG. 9 plots average power required to achieve higher traffic demands for the example FIG. 7 network topology;

FIG. 10 illustrates an example hierarchical network topology for application of methods of the invention and used in a numerical simulation of an embodiment of the invention; and

FIG. 11 plots the ratio of the total maximum throughput for a routing policy produced by application of methods of the invention versus that using only minimum energy paths as a function of ambient noise and in the example topology of FIG. 10.

Please replace the paragraph beginning on page 22, line 14, with the following rewritten paragraph (note, all page and line numbers refer to Applicant's original submission):

We consider a large fully connected wireless network consisting of 80 nodes and 150 links as shown in FIG. 1, distributed over a 200m x 200m field. The network was divided into 16 clusters labeled by integers 1, 2,...16, and each cluster consists of 5 or 6 nodes and 8 or 9 links. A link belongs to a cluster if the transmitting node is within or on the boundary of that cluster. Moreover, each link in the network belongs to exactly one cluster. The minimum average rate on all links in the network is set to the same value. The peak power of all links is identically set to 1 Watt and $W' = 10^6$. We applied our hierarchical approach over the entire network by dividing it into edge sets in 3 different ways denoted by cluster schedules X, Y and Z. Cluster schedule X schedules a single edge set containing all 16 clusters. Cluster schedule Y schedules two edge sets each consisting of clusters in a checker board pattern. i.e., {1,3,6,8,9,11,14,16} and

{2,4,5,7,10,12,13,15}. Each edge set in Y is scheduled for half the time. Cluster schedule Z schedules four edge sets containing clusters {1,3,9,11}, {2,4,10,12}, {5,7,13,15} and {6,8,14,16} for a fourth of the time each. We plot the total average transmit power consumed by all the links in the network as a function of the (minimum) network throughput for each cluster schedule in FIGs. 2 and 3 corresponding to different values of thermal noise n = 0.05m W and n = 0.2 mW respectively. The thermal noise at all receivers is the set to be the same.

Please replace the paragraph beginning on page 23, line 3, with the following rewritten paragraph:

We find that for very low data rates (between 0 to 41 Mbps in FIG. 3) it is energy efficient to enable all the 16 clusters simultaneously, regardless of the value of thermal noise. As the data rate along links increases (between 41 to 78 Mbps in FIG. 3), cluster schedule Y is the most energy efficient of the three configurations considered. For data rates beyond 78 Mbps (in FIG. 3), the energy efficient strategy is to enable the cluster schedule Z. For both values of thermal noise, Z is capable of supporting higher throughput than that achievable by X and Y.

Please replace the paragraph beginning on page 23, line 11, with the following rewritten paragraph:

For low rates, the optimal strategy in each cluster is a simple TDMA of links with long idle times. Therefore, the intercluster interference is small even when clusters are next to one another, making cluster schedule X the most energy efficient. However as the data rate requirement on links increases, links in each cluster are active for longer durations resulting in

higher intercluster interference. In this case, schedules Y or Z are more energy efficient. We observed similar results to that in FIG. 6 for randomly generated network topologies as well.

Please replace the paragraph beginning on page 23, line 18, with the following rewritten paragraph:

Observe that by selecting a schedule based on the rate requirement we can realize an energy versus rate graph which is the minimum of the curves corresponding to the cluster schedules X, Y and Y in FIG. 6. In fact, by suitable timesharing of the cluster schedules we can achieve any rate in FIG.6 which lies in the convex hull of the minimum of the three cluster schedule curves.

Please replace the paragraph beginning on page 24, line 6, with the following rewritten paragraph:

A string topology consists of a row of nodes connected by means of directed links as shown in FIG. 4. This topology is useful as a transport network to carry data through short hops but over potentially long total distances through relay nodes. Node 1 is the source of data and node 5 is the sink. Each node in this example has an omnidirectional antenna, and all nodes have identical peak transmission power constraints of 1 Watt. The path-loss between nodes is modeled as an inverse square of the distance, i.e., $G(i,j)=\frac{1}{d(i,j)^2}$. The ambient noise power at all the nodes is assumed to be constant. We compare the maximum throughput of the single session between node 1 to node 5 achieved by our link scheduling policy to a TDMA scheduling policy. The TDMA policy schedules exactly one link at a time, activating each link at maximum power for a fourth of

the time. We plot the ratio of throughputs achieved by the our link scheduling algorithm to TDMA with increasing values of ambient noise in FIG. 5. The ambient noise is normalized with respect to the peak received power (from a single transmitter) in the network and is scaled by $\log_2(.)$ (for this and the remaining examples). The maximum throughput achieved by our policy is higher than TDMA for all values of ambient noise. In low noise regimes, TDMA is a near-optimal policy. However, as the level of ambient noise at nodes increases, the gains in throughput of our policy increase significantly. The optimal policy schedules multiple transmissions at the same time, even in fairly low ambient noise regimes, thereby exploiting spatial reuse and thus outperforming TDMA. This effect is more pronounced in moderate and high ambient noise regimes where the optimal policy schedules concurrent transmissions even though they are in close geographic proximity.

On page 25, please insert the following paragraph beginning on line 1 as follows:

To get a sense of how energy efficient the optimal policy is as it supports increasing traffic demands, we plot the total average power with increasing traffic rates for the session between node 1 and node 5 in FIG. 6. For this experiment, we fix the level of the logarithm of the normalized value of ambient noise to -0.67. This value corresponds to the 3rd data point on the x-axis in FIG. 5. We also set $W' = 10^7$.

Please replace the paragraph beginning on page 25, line 7, with the following rewritten paragraph:

FIG. 6 indicates~~We also found~~ that the total minimum average power is a linear function of the traffic demand for average rates below 4 Mbits/sec. Below 4 Mbits/sec, our

scheduling method functioned essentially as TDMA. Specifically, only one link is active at any time, each link is active for the same fraction and for some fraction of time all links are idle. As the traffic demand of the session increases beyond 4 Mbits/sec, the total average power increases at a faster rate. For traffic load between 4 Mbits/sec and 4.98 Mbits/sec, the transmission modes in the optimal policy are given by [{(1,2)}, {(2,3)}, {(3,4)} and {(1, 2), (4, 5)}]. For traffic loads above 4.98 Mbits/sec to the maximum throughput possible, the optimal transmission modes are [{(1,2)}, {(2,3)}, {(3,4)}, {(1,2),(3,4)} and {(1,2),(4,5)}]. We see that in order to support high traffic loads, the optimal link scheduling policy activates a large number of links simultaneously. Note that the transmission modes in the optimal policy are half-duplex. Therefore, transmissions in the optimal schedule cannot consume a total average power of more than 2000 mW for this topology.

Please replace the paragraph beginning on page 25, line 26, with the following rewritten paragraph:

We also consider an asymmetric diamond topology <u>as shown in FIG. 7</u> to illustrate the substantial increase in throughput by splitting traffic over multiple routes including paths that are energy inefficient. Nodes in this topology are equipped with omnidirectional antennas, and the peak transmission power each node is fixed at 1 Watt. Node 1 is the only source of data and node 4 is the sink. We assume $G(1,4)=\frac{1}{d(1,4)^4}$; the path loss between all other nodes is given by the inverse square law of distance. We consider our integrated routing and scheduling algorithm over this diamond topology, where all possible routes from the source to the destination are allowed except for the single hop route (1,4). For comparison purposes, we also considered our scheduling

algorithm where only the links (1,2), and (2,4) are allowed to be used, which corresponds to routing over a single minimum energy path $1 \rightarrow 2 \rightarrow 4$.

Please replace the paragraph beginning on page 26, line 7, with the following rewritten paragraph:

We compared the ratio of throughputs for these <u>in FIG. 8</u> policies. Clearly, using multiple paths yields higher throughputs for all values of ambient noise. The increase in throughput by splitting traffic over multiple paths is significant even for moderate levels of ambient noise. This result is somewhat surprising since all links are sharing a common bandwidth and we have a per-node peak power constraint. An intuitive explanation of this is that by splitting the traffic over both paths, the transmission modes {(1,2),(3,4)} and {(2,4),(1,3)}, which do not have much interference can be alternated in time. This results in substantial delivery of data to the destination in every slot. If we only allow the path $1 \rightarrow 2 \rightarrow 4$, in order to avoid self interference, the links (1,2) and (2,4) must be active one at a time, so that node 4 will only be delivered data in every other slot.

Please replace the paragraph beginning on page 26, line 18, with the following rewritten paragraph:

<u>To illustrate energy efficiency issues, we plot the total minimum average power with increasing traffic demand at node 1 in FIG. 9. The logarithm of the normalized value of ambient noise for this point is 0.45 and corresponds to the *3rd* data point on the x-axis in FIG. 8. We set $W' = 10^7$.</u> The maximum data rate achieved by TDMA using the minimum energy path $1 \rightarrow 2 \rightarrow 4$ is 3.65 Mbit/sec. In comparison, our policy is capable of supporting a data rate of up to 5.05

Mbits/sec by using both the minimum energy path as well as the non-minimum energy path. For traffic loads below 3.65 Mbits/sec, our method produces a policy that functions as TDMA over the path $1 \rightarrow 2 \rightarrow 4$. As the traffic load increases beyond 3.65 Mbits/sec, the method results in an optimal policy that starts using both paths by scheduling transmission modes $\{(1,2),(3,4)\}$ and $\{(1,3),(2,4)\}$ in addition to TDMA transmission modes. The average power required to achieve higher traffic demands beyond 3.65 Mbits/sec increases with a greater slope as can be seen in FIG. 9. The maximum throughput of 5.05 Mbits/sec is achieved by splitting traffic by using both paths and scheduling transmission modes $\{(1,2),(3,4)\}$ and $\{(1,3),(2,4)\}$ for a dominant fraction of time and scheduling transmission modes $\{(1,2)\}$, $\{(2,4)\}$ for the remaining time. The optimal policy transmits a fair amount of traffic on both available paths, but transmits a greater share of its traffic on its minimum energy path. We have noted a 10 to 20% reduction in the throughput gains of the optimal policy than what is shown in FIG. 8 for the case when $G(1,4)=\frac{1}{d(1,4)^2}$.

Please replace the paragraph beginning on page 27, line 10, with the following rewritten paragraph:

A hierarchical topology as shown in FIG. 10 represents a complex topology such as an access network, where the number of nodes in each tier decrease as we get closer to the access point node 6. This experiment highlights the significant gains in throughput by jointly routing and scheduling to an alternative policy that optimally schedules links over pre-determined minimum energy routes. Nodes 1, 2 and 3 are sources of data and node 6 is the sink. We assume $G(1,6)=\frac{1}{d(1,6)^4}$ and $G(2,6)=\frac{1}{d(2,6)^4}$; the path loss between all other nodes is given by the inverse

square law of distance. The minimum energy paths for the source nodes are: $\{1 \rightarrow 3 \rightarrow 6\}$, $\{2 \rightarrow 3 \rightarrow 6\}$ and $\{3 \rightarrow 6\}$ respectively. Our integrated routing and scheduling algorithm is allowed to utilize all possible paths to route their data to node 6. We constrain the rates of each source to be identical. We plot the ratio of the total maximum throughput of our routing policy to that achieved by using only the minimum energy paths, as a function of ambient noise in FIG. 11.